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SPECTRA FROM THE WEHNELT INTERRUPTER.

By Harry W. Morse.

With Three Plates.

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SPECTRA FROM THE WEHNELT INTERRUPTER. I.

By Harry W. Morse.

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Nearly every one who has written on the subject of the electrolytic interrupter of Wehnelt has noticed and described the brilliant light which is produced about the "active" electrode when the interrupter is in action. Wehnelt himself * examined this light, and states that he found in its spectrum lines of hydrogen, the D-lines of sodium, and, when the active electrode was made negative, many other bright lines. Voller and Walter † made a more complete qualitative study of the spectra, and found that apparently any metal, when used as active electrode in the Wehnelt arrangement, gave its characteristic spectrum. They speak also of the fact that it was necessary to frequently change the electrolyte, as the metal which had been used in preceding experiments as active electrode contaminated succeeding spectra, and showed its own lines together with those of the metal under examination. These same facts have been brought out more fully, though still in a very crude and qualitative way, by Hoppe ‡ and Werner von Bolton §, both of the latter suggesting the use of the phenomenon for producing colored light and spectra for demonstration. Simon ‖ states that in the form of interrupter which he used, in which the break takes place, not at a metal point, but in the electrolyte at a narrow opening in a dividing diaphragm between two large electrodes, the same light-phenomena are produced, but no further data on the spectra are given. Hale ¶ examined the spectrum of an iron point in the Wehnelt interrupter in connection with other spectra produced by the arc under liquids. Konen,** in a paper on the same subject, also speaks of these

* W. A., **68**, 233 (1899).
† W. A., **68**, 539 (1899).
‡ Electrotech. Ztsch., **21**, 507 (1900).
§ Ztsch. f. Electrochem., **9**, 913 (Nov. 1903).
‖ W. A., **68**, 860 (1890).
¶ Astrophys. J., **15**, 131 (1902).
** Drudes An., **9**, 742 (1902).

spectra, but appears to consider the light too feeble to permit of photography of the spectrum.

The present paper contains the first part of a research on the spectra produced by an arrangement similar to the Wehnelt interrupter, with tables of the wave-length and approximate intensities of lines of the following metals, together with comparison tables and plates of lines produced in the arc and condensed spark: —

Lithium. Carbon point in solution of lithium chloride.
Sodium. Carbon point in solution of sodium chloride.
Potassium. Carbon point in solution of potassium chloride.
Magnesium. Wire in hydrochloric acid.
Calcium. Platinum point in solution of calcium chloride.
Strontium. Platinum point in solution of strontium chloride.
Barium. Platinum point in solution of barium chloride.
Aluminium. Wire in hydrochloric acid.
Silver. Wire in hydrochloric acid.
Zinc. Wire in hydrochloric acid.
Mercury. Platinum point in solution of mercuric nitrate.
Tin. Wire in hydrochloric acid
Lead. Wire in hydrochloric acid.

It is the intention to present in this paper the more general study of the phenomena, and those spectra have therefore been selected from the plates at hand which are simplest and show marked points of interest.

At first sight of the phenomenon one is reminded of the production of spectra by allowing the spark to pass from a platinum point *to* a solution of a metallic salt, and the spectra do show marked similarity to those produced in this way. The researches on the mechanism of the interrupter have shown, however, that the breaking of the circuit is caused by the formation of a layer of vapor about the active point and that the water of the solution is in large measure dissociated by the high temperature reached.* There seemed therefore the possibility that we might possess in an arrangement of this kind another step in our scale of spectra and possibly a temperature midway between that of flame and arc, or arc and spark.

The importance of a more thorough study of spectra produced under water and in gases and vapors under pressure, and the fact that among von Bolton's drawings of spectra of the Wehnelt interrupter there are several which are *banded*, gave interest to a more exact study of the phenomena.

* Vid. Voller and Walter, l. c.

In order to reach some degree of accuracy in the comparison of wave-lengths the spectra were photographed with a Rowland concave grating of 163 cm. radius, of about 2500 lines to the cm. This grating has a ruled surface of 8 × 14.5 cm. and gives a very bright spectrum indeed. The dispersion is of course small, the length of the first spectrum from λ 3200 to λ 6000 being only about 5 cm. This grating was kindly loaned us by Professor Langley and has proven indispensable for the work.

The instrumental arrangements were simple. The Wehnelt cell was made of a beaker, the large electrode of platinum, lead, or aluminium, and the point was a wire of the metal under investigation, or where the metal was in solution as a salt, of platinum or carbon. In this latter case the platinum lines or the lines of impurities in the carbons used often appeared, and they were used as standards with which to compare the spectrum sought. The lines of the metal forming the large plate also appeared after a prolonged exposure. The image of the light about the point was focussed on the slit by means of a condensing lens of aperture sufficient to fill the whole of the large grating with light.

The exposures required were long, as the light is at best weak compared with that of the spark or arc or even that of a Geissler tube. For a slit opening of 0.10 mm. the exposure in the first spectrum was from one to two hours. In the third spectrum, where photographs were taken for the more accurate comparison of wave-lengths, the exposure reached six hours, the intensity of the light varying greatly with different metals.

The spectra were photographed on orthochromatic plates, without color screen, and the range of most of the photographs is from λ 3200 to λ 6000. In some cases the photograph extends much farther into the red, the line of lithium at λ 6709 being, for example, clearly visible. The plates were developed with Amidol, to which only a very small amount of sodium sulphite and a little potassium bromide were added. This developer acts slowly, but permits of prolonged development without the production of chemical fog. It is to be highly recommended for work of this kind, where under-exposure is the rule and every possible detail must be obtained from the plate.

During the exposure the light was observed frequently with a direct vision spectroscope, and the various parts of the glowing gaseous envelope about the point were examined in the hope of finding differenences in the spectrum at various points. Such differences were not found, the spectrum being apparently the same in all parts of the envelope and remaining remarkably constant throughout the exposure.

As the electrolyte became hot the intensity of the light became less, and for the sake of economy in time the solution was usually changed every ten or fifteen minutes. The points of most of the metals used also required frequent replacing, and this was done by feeding the wire down through a simple clamp as fast as it was eaten away.

The first series of observations showed that the spectrum is exactly the same, whether the metal in question is used as active electrode or is present as a salt in solution; further, whether the metallic point is anode or cathode, though a great difference in the intensity of the light exists in the two cases. The metallic point as anode gives only a feeble zone of light. As cathode several distinct stages of the condition about the point are to be distinguished, one of these being accompanied by a rapid "zerstäubung" of the metal. This condition is unfavorable for the production of a bright luminescence, but goes over with increase of current density into the more favorable condition.

It was found that the spectrum is exactly the same whether produced by direct or alternating current. With direct current the electrolyte heated faster and the point was more rapidly eaten away. The greater part of the work was therefore carried out with the commercial alternating current, which is of 110 volts and 60 cycles. The current through the cell averaged 2.5 amperes, and it was found best to keep the resistance of the electrolyte at a point which would give about this current. The large plate had a contact surface of about 10 sq. cm. and the wires used were of diameter 0.3 to 1.5 mm.

No direct experiment on the effect of inductance in the circuit was made, but the cell was used alternately without inductance and as interrupter with a large induction coil for the production of the spark spectra, without any change visible in the small direct vision spectroscope.

It was expected that many gaseous lines would appear, and they were looked for, but the only one found under the conditions of the experiment was the red hydrogen line at λ 6562.* This is visible clearly in many cases; in others it is either very faint or entirely invisible.

In the following tables the wave-lengths of the principal lines are given, with their intensities in the spark, arc, and Wehnelt spectra on a scale of 1 to 100; 1 is the intensity of a barely measurable line, and 100 that of very strong lines, like the principal lines of the alkali- and alkaline earth-metals. It is of course clear that such intensity measure-

* Werner von Bolton used the hydrogen lines of the Wehnelt as standards for comparison, and shows them in his drawings of spectra. Certainly none appear on any of the author's plates.

ments with the eye, on plates where the exposures are by no means comparable, are only rough approximations. The attempt has therefore been made to confine any conclusions drawn from such comparisons to cases so obvious and striking that there could be no possible chance of error introduced by difference in exposure or width of slit.

Careful comparison of the spectra produced by a platinum or carbon point in solutions of various salts of the same metal shows that there are no differences whatever corresponding to different salts. This has been proven for zinc by photographing the spectrum of a platinum point in zinc sulphate, nitrate, chloride, bromide, and iodide, and also that of a zinc point in sulphuric, nitric, and hydrochloric acids. These spectra are all identical within the limits of the method. The same has been shown for aluminium for an equally extended series of salts and acids, and in the cases of other metals for a less number of combinations. The tables give the data for a stated combination in each case, but apply equally well to any other for the same metal or for any salt of the same metal.

The present paper is concerned only with the photographs of the Wehnelt in the first spectrum, where comparison can be made with the full spectrum of spark and arc without disturbance from overlapping. The dispersion is only sufficient to give an accuracy of about 1 Ångstrom unit in the comparison of wave-lengths.

LITHIUM. [Plate 2, Fig. 7.]

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3233.0	6	10	2	4273.5	5	30	5
3795.0	. .	5	. .	4602.5	100	100	100
3915.0	. .	8	. .	4972.0	40	50	15
3986.0	. .	8	. .	6104.0	10	20	30
4132.5	15	100	10	6708 0	. .	2 rev.	5

Spark. Lithium chloride on carbon electrodes.

Arc. Lithium chloride on carbon electrodes.

Wehnelt. Carbon point in solution of lithium chloride. (The impurities in the carbon are iron, calcium, and aluminium.)

It seems probable that the exposure of the Wehnelt is at least as great in proportion as the others, since the line at λ 6708 comes out clearly and lines of shorter wave-length than λ 3233 are visible.

The resemblance to the spark spectrum is striking, but there are considerable differences in intensities, λ 4972 being much weaker and λ 6104 much stronger. Many of the strong *arc* lines are either absent or greatly reduced in intensity. It is of interest to note that the lines which retain a part of their intensity belong to the principal and first subseries of Kayser and Runge, while those which lose all or a great part of their intensity from arc to Wehnelt belong to the second subseries. The lines λ 4972.0, λ 4273.5, λ 3986.0 are of this latter class.

SODIUM.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3303.0	15	40	10	5688.0	15	40	30
4983.0 d	. .	10	. .	5890.0	50	50 rev.	50
5155.0 d	. .	4	. .	5896.0	40	40 rev.	50
5682.5	15	15	10				

Spark. Sodium chloride on carbon electrodes.

Arc. Metallic sodium on carbon electrodes.

Wehnelt. Carbon point in solution of sodium hydroxide. (Impurities same as in lithium.) (Plate 1, Fig. 2.)

A rather close agreement with the spark spectrum is to be seen, with a noticeable difference in the relative intensities of the lines at λ 5682 and λ 5688. The lines which are present in the arc spectrum and do not appear in the Wehnelt spectrum belong in this case also to the second subseries, but it is quite probable that the exposure was insufficient to bring out these relatively weaker lines. λ 5896 is at least as strong as λ 5890. Taking into account the rapid decrease in the sensitiveness of the plates in this region, it must in reality be stronger.

POTASSIUM.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3217.5	..	3	..	5340.0	2	20	6
3447.0	..	40	20	5343.5	1	..	..
4044.5	30	100	100	5359.5	..	15	6
4047.0	..	..	..	5783.0	3	20	6
5099.5	..	4	1	5802.0	3	20	10
5112.5	..	3	1	5812.5	..	3	1
5323.5	2	10	3	5832.0	2	10	6

Spark. Potassium chloride on carbon electrodes.

Arc. Metallic potassium on carbon electrodes.

Wehnelt. Carbon point in solution of potassium carbonate. (Impurities in carbons same as in lithium.) (Plate 1, Fig. 3.)

The spectrum resembles the arc more closely than the spark. The difficulty of obtaining the spark spectrum unobstructed by air lines and the lack of a resolution of the doublets make comparisons in the case of little value.

MAGNESIUM.

In the table the following points are of especial interest:

1. The triplet λ 3720, λ 3724, λ 3730. These lines do not appear in the spark or arc spectrum under ordinary circumstances, but are strong in the spectrum of magnesium in the oxyhydrogen flame, and have always been considered lines belonging to a low temperature. Liveing and Dewar* observed that when the arc passed between electrodes of metallic magnesium these lines were visible, provided the atmosphere about the arc was one which could provide oxygen. They come out clearly in air, oxygen, and carbon dioxide, but do not appear in hydrogen, nitrogen, cyanogen, chlorine, or ammonia.

2. The presence of the arc line at λ 4352 and the strong spark line at λ 4481. One or the other of these is usually very faint under ordinary conditions. In the arc between magnesium electrodes both lines are strong, λ 4481 sometimes quite as strong as in the spark.* Hart-

* Proc. Roy. Soc., **32**, 189 (1881); and ibid., **44**, 241 (1888).

MAGNESIUM. [PLATE 2, FIG. 8.]

Wave-l'gth.	Spark.	Arc.	Flame.	Wehnelt.	Wave-l'gth.	Spark.	Arc.	Flame.	Wehnelt.
3330.0	7	8	. .	7	4966.5	. .	. .	. .	4
3332.5	10	10	. .	10	4974.5	. .	. .	. .	b
3337.0	12	15	. .	12	4984.5	. .	. .	. .	b
3341.0	. .	. .	. .	2	4995.0	. .	. .	. .	b
3437.5	15	. .	. .	. .	5006.0	. .	. .	. .	b
3720.0	. .	. .	strong.	10	5020.0	. .	. .	. .	b
3724.0	. .	. .	strong.	15	5028.3	. .	. .	. .	b
3730.0	. .	. .	strong.	20	5036.0	. .	. .	. .	b
3829.5	20	10	strong.	20	5063.0	. .	. .	. .	b
3832.5	30	15	strong.	30	5072.0	. .	. .	. .	b
3838.5	40	20	strong.	40	5079.5	. .	. .	. .	b
3855 0	. .	. .	. .	1	5086.5	. .	. .	. .	b
4352.0	3	12	. .	5	5168.0	. .	20	. .	20
4443.5	. .	. .	. .	b	5172.5	5	30	. .	30
4449.0	. .	. .	. .	b	5183.0	5	50	. .	50
4481.0	30	. .	. .	30	5527.5	4	. .	. .	8
4570.0	. .	1	strong.	. .	5529.0	. .	20	. .	. .
4704.0	4	15	. .	6	5711.0	. .	8	. .	. .
4960.5	. .	. .	. .	10	5880.0	. .	. .	. .	b

Spark. Magnesium terminals.
Arc. Metallic magnesium on carbon electrodes.
Flame. Liveing and Dewar's measurements.
Wehnelt. Magnesium wire in hydrochloric acid.

mann and Eberhard* have shown that in the spectrum of the arc between magnesium terminals under water, spark lines become strong, λ 4481 showing clearly. Hartmann† has also shown that there is reason to doubt that λ 4481 corresponds to a higher temperature than

* Astrophys. J., **17**, 229 (1903). † Ibid., **17**, 270 (1903).

λ 4352. The spectrum of the arc between magnesium terminals in an atmosphere of hydrogen is nearly identical with that produced under water.*

3. The absence of certain strong lines in the Wehnelt spectrum. Among these the arc line λ 5529, the flame line λ 4570, the spark line λ 3437.5. The presence of other lines usually appearing, and supposed to correspond to the same temperature, is also of importance.

4. The presence of the bands usually ascribed to the oxide. In the band with head at λ 5006 seven flutings are visible. These are also visible in the arc spectrum, but are much fainter. This band was described by Liveing and Dewar † and resolved into fine lines by Crew and Basquin. ‡ The first-named authors obtained the band only in oxygen, air, or carbon dioxide, and the evidence seems to show conclusively that it is due to the oxide. It seems clear from Liveing and Dewar's work that the presence of this band does not necessarily indicate a lower temperature than that corresponding to the other lines of the spectrum of magnesium. This band also appears when the spark is allowed to pass from a platinum point to a solution of a magnesium salt. §

5. The *appearance* of certain lines. The line at λ 4481 is perfectly sharp, as it is when inductance is introduced into the circuit of the spark in air. ‖ The triplet λ 3829.5, λ 3832.5, λ 3838.5 is very intense, and the lines are broadened and diffuse in contrast to their appearance in air. Wilsing ¶ finds that when the arc passes between magnesium terminals under water, this triplet is displaced, and broadens out into diffuse absorption bands.

Calcium.

The spectrum is very like that of calcium in the spark, with many differences of intensity, and absence of some fairly strong lines. The spectrum from λ 5500 to λ 5900 is of interest. There is evident diffuseness in the lines in this region, in marked contrast to the sharp lines of the spark and arc, but whether this is due to a real difference in the spectra or a possible lack of adjustment of the apparatus a more extended investigation must decide. So far as the plates obtained show, there are bands with heads corresponding to sharp lines in the arc and spark spectra.

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* Astrophys. J., **17**, 229 (1903). † L. c.
‡ Astrophys. J., **2**, 101 (1895).
§ Vid. Lecoq de Boisbaudran, Spectres Lumineux.
‖ Vid. Huggins, Astrophys. J., **17** 145 (1903).
¶ Astrophys. J., **10**, 113 (1899).

CALCIUM.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3170.5	20	..	..	4878.5	5	8	..
3275.0	..	8	..	5041.5	3	4	..
3631.0	5	30	2	5189.0	3	4	..
3644.5	10	20	2	5262.5	3	4	3
3706.5	50	10	20	5265.7	2	6	2
3737.5	50	25	30	5270.5	5	10	..
3933.5	100	100	60	5349.5	3	5	..
3968.5	60	70	40	5472.0	..	2	b?
4227.0	40	100	30	5500.0	2	3	b?
4283.0	6	10	5	5537.0	..	..	b?
4289.5	4	10	5	5582.0	3	6	b?
4299.0	3	5	3	5589.0	10	10	15
4302.5	5	8	8	5594.0	4	6	b?
4308.0	3	8	3	5598.5	4	4	b?
4319.0	7	10	3	5601.5	3	3	b?
4425.5	7	15	3	5603.0	3	2	b?
4435.5	10	20	8	5857.5	..	5	4
4455.0	15	30	15				

Spark. Calcium chloride on carbon electrodes.
Arc. Calcium chloride on carbon electrodes.
Wehnelt. Platinum point in calcium chloride solution.

STRONTIUM.

The spectrum is in general similar to that of the spark, the order of intensities agreeing well in the majority of instances. A few of the stronger spark lines, with intensities sufficient to make them visible if they were present in normal intensity, are not to be seen. Among these the group λ 5225–λ 5257. The "oxide" bands are bright.

The same question arises here as in the case of calcium. In the

STRONTIUM.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3381.0	30	8	5	4869.0	4	..	..
3465.0	40	10	20	4874.0 d	5	5	5
3475.0	10	8	3	4893.0	2	..	..
3706.0	..	10	3	4962.0	7	8	3
4030.0	..	8	..	4968.0	2	4	..
4078.0	100	50	50	5221.5	2	..	..
4162.0	15	5	6	5224.0	2	..	..
4215.5	100	40	40	5238.5	2	5	..
4303.0	..	2	..	5256.5	3	5	..
4306.0	40	4	20	5456.5	3	..	..
4319.0	..	8	..	5480.5	8	..	..
4438.0	..	30	..	5485.0	1	..	b?
4531.5	..	5	..	5504.0	6	..	b?
4607.5	25	50	30	5520.5	4	..	..
4722.5	5	10	5	5534.0	20	..	b?
4742.0	5	10	3	5540.0	3	..	..
4784.0	3	8	2	5587.0	..	..	b?
4812.0	7	10	6	5850.0	4	..	..
4832.0	6	10	3	5890.0	..	..	b?
4855.0	2	..	..	5895.0	..	..	b?

Spark. Strontium chloride on carbon electrodes.
Arc. Strontium chloride on carbon electrodes.
Wehnelt. Platinum point in solution of strontium chloride. (Plate 1, Fig. 5.)

Wehnelt spectrum of strontium there are diffuse bands in the yellow and yellow-green with maxima which seem to correspond closely with sharp lines in the spark spectrum. Whether or not greater dispersion will show these to be really bands with heads in the same places as are occu-

pied by sharp lines in the other spectra the plates at hand give insufficient evidence. A more exact study of these bands and the similar ones in the calcium spectrum offers great interest.

BARIUM.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3377.0	. .	8	. .	4674.0	2	5	2
3420.5	. .	10	6	4691.0	1	5	. .
3501.0	5	15	. .	4727.0	1	10	. .
3525.0	. .	6	. .	4900.0	30	. .	30
3545.0	. .	6	. .	4903.0	. .	10	. .
3892.5	50	8	50	4934.0	80	30	100
3910.0	. .	8	2	5160.0	. .	10	. .
3993.5	5	15	3	5424.0	. .	40	5
4131.0	40	40	60	5519.0	5	30	6
4166.0	15	10	15	5534.0	20	80	100
4283.5	. .	20	3	5620.0	. .	10	. .
4351.0	. .	20	2	5680.0	. .	8	. .
4403.0	3	10	3	5778.0	. .	50	5
4432.0	3	8	5	5800.5	. .	10	. .
4506.0	2	4	4	5826.0	. .	10	2
4525.0	30	30	30	5854.0	8	10	8
4554.0	100	100	100	6142.0	. .	2	5
4580.0	. .	5	4				

Spark. Barium chloride on carbon electrodes.
Arc. Barium chloride on carbon electrodes.
Wehnelt. Platinum point in solution of barium chloride. (Plate 1, Fig. 4.)

The above comparison table for barium does not include the bands in the green which are strong in the spectrum of the Wehnelt. The following table gives the approximate position of these bands.

BANDS IN THE WEHNELT SPECTRUM OF BARIUM.

Wave-lengths.	Wave-lengths.
4570	5272.0 (red edge of same fluting).
to	5325.0 head of fluting (red edge).
4575.	5446.0
4598	to
to	5462.0
4605.	5477.0 centre of band.
5134.0 centre of band.	5497.0
5167.0 centre of band.	to
5242.0 head of fluting (violet edge).	5519.0 (line. Intensity 6).

The spectrum produced about a platinum point in a solution of barium chloride is in many points similar to the spark spectrum. Many arc lines, absent from, or extremely weak in the spark spectrum, make their appearance. λ 3910.0, λ 4283.0, λ 4351.0, λ 4580.0, λ 5425.0, λ 5778.0, are examples. At the same time many strong arc lines are absent in the Wehnelt spectrum, which has the appearance of a rather incomplete composite of arc and spark spectrum so far as the *line* spectra are concerned. The brightness of the "oxide" bands in the green is remarkable. Altogether the spectrum of the Wehnelt is much like that produced by sparking from a platinum point to a solution of a barium salt. (Vid. Lecoq, l. c.)

Aluminium.

The spectrum of an aluminium point as active electrode in an acid or an alkali or a salt solution, and that from a platinum point in a solution of an aluminium salt, seem to be exactly the same as that obtained by allowing a spark discharge without condenser to pass in air between aluminium terminals. The author has obtained the same banded spectrum in tubes containing oxygen at a pressure of a few millimeters of mercury, and with the same distinctness in tubes containing hydrogen at low pressures, by allowing the spark, condensed or uncondensed, to pass between aluminium terminals. In the case of tubes filled with hydrogen the bands persist for only a comparatively short time, and the spectrum of hydrogen remains. The same spectrum, with the exception of some lines not belonging to the bands, is obtained from aluminium in the arc.

Hasselberg * has measured a great number of lines in these flutings,

* Kon. Svensk. Akad., 24.

ALUMINIUM. [Plate 2, Fig. 9.]

Wave-length.	Spark.	Arc.	Wehnelt.
3587.0	50	20	25
3602.0	30	4	4
3612.5	15	..	2
3702.5	2	..	..
3714.0	8	..	2
3944.0	50	60	50
3961.5	100	100	100
4034.3			
4083.7			
4243.2			
4262.5			
4271.8			
4274.0			
4276.6			
4279.3			
4282.7			
4306.8			
4332.0			heads of flutings in Wehnelt spectrum.
4341.7			
4354.3			
4371.7			
4375.6			
4384.6			
4395.6	.....	.....	.....
4414.8			heads of flutings in arc spectrum.
4432.5			
4448.0			
4464.0			
4472.0			
4480.0	.....	.....	.....
4495.3			
4512.2			
4517.7			
4530.0			
4538.7			
4558.9			
4577.6			
4595.0			
4608.4			
4625.9			
4642.3			

Wave-length.	Spark.	Arc.	Wehnelt.
4648.5			
4662.8			
4671.9			2d band. Heads.
4695.2			
4717.1	.....	.....	
4736.9			
4755.1			
4782.6			
4803.3			
4817.8			
4842.0			
4861.0			
4866.6			3d band. Heads.
4889.6			
4951.6			
4960.1	.....	.....	
4980.1			
4994.0			
4999.5			
5011.0			
5017.8			
5080.6			
5093.3			
5102.7			
5111.4			4th band. Heads.
5118.1			
5124.0			
5142.6	.....	.....	
5148.0			
5161.0			
5176.0			
5190.0			
5262.0			
5207.6			
5222.4			
5328.5	.....	.....	bands.
5337.0			
5465.0			
5593.0		5	5 lines.
5697.0		3	3
6234.0		..	3
6244.0		..	5

and his measurements have been used for comparison, the agreement being as close as could be expected from the small dispersion and poor definition of the plates measured.

These bands have been for many years attributed to the oxide, but there exists a considerable amount of evidence contradictory to this view. Arons * found this same banded spectrum in the arc between aluminium points in an atmosphere of nitrogen or hydrogen, and concluded that the banded spectrum corresponds to the metal and not to the oxide. Hemsalech † agrees with Arons, and he has shown that by introducing inductance the line spectrum of the spark between aluminium terminals in nitrogen changes into this same banded spectrum. Berndt ‡ concludes from his experiments that the presence of oxygen is necessary for the production of the bands. Lockyer also attributes the bands to the oxide, Wüllner to the metal, Kayser to the oxide, etc.§ Simple experiments of the author in hydrogen in closed tubes have shown that the band spectrum, which is present in considerable strength when the discharge is first sent through the tube, decreases rapidly and disappears in a short time, to appear again after the tube has been allowed to recover for a time. The simplest apparent explanation is that the oxide coating of the aluminium terminals reacts with the hydrogen under the influence of the spark with the formation of water vapor, probably until equilibrium between metallic aluminium, aluminium oxide, hydrogen and water vapor is reached. On standing the oxide is re-formed and the equilibrium at the lower temperature re-established.

The tendency already spoken of under barium, toward a composite of arc and spark spectra, is very evident in the case of aluminium. Not only are the bands and lines of the arc spectrum present, but also several lines which do not belong to it.‖ Most of the lines of the spark spectrum are present in the Wehnelt, some of them with changed intensities. The general appearance is as though a rather weak spark spectrum had been superimposed over a stronger arc spectrum.

It is the intention of the author to return to this and other band spectra of the Wehnelt in a later paper. The intensity of the light from an aluminium point in hydrochloric acid is sufficient to permit of a photograph with a grating of higher dispersion without an excessively long exposure. The spectrum being free from the overlapping carbon bands

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* Drude's Ann., **1**, 700 (1900). † Ibid., **2**, 331 (1900).

‡ Ibid **4**, 788 (1901). § Vid. references, Hemsalech, l. c.

‖ Vid. Kayser and Runge, W. A., **43**, 126.

of the arc, the long band in the violet, which was not examined by Hasselberg, should be very easy of access.

SILVER.

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3281.0	60	50	30	3982.0	..	3	..
3330.0	..	..	2	4055.5	1	15	5
3358.9	..	..	2	4212.0	1	10	10
3383.0	60	50	50	4228.5	..	..	1
3546.5	..	2	1	4312.0	1	..	1
3583.0	..	2	2	4476.0	1	12	8
3639.5	..	..	1	4668.5	..	15	10
3682.0	1	15	1	4875.0	1	..	1
3781.0	..	..	1	5209.0	100	50	40
3811.0	..	..	1	5402.0	20	..	..
3892.0	4	..	..	5465.0	..	50	100
3907.5	..	1	1	5471.5	..	20	..
3943.0	1	1	..	5709.0	10	..	..
3963.0	..	..	2				

Spark. Silver electrodes.
Arc. Metallic silver on carbon electrodes.
Wehnelt. Silver wire in hydrochloric acid.

With silver as active electrode striking differences of intensity from those obtained in the spark and arc are the rule. Only a few lines come out strongly enough to be reproduced, and the spectrum is in general more like that of the arc than that of the spark. This is shown by the lines at λ 4055.5, λ 4212.0, λ 4476.0, λ 4668.0, λ 5465.0. A number of lines which are strong in the arc are not visible, as, e. g., λ 5471.0, and others are much weaker, like λ 3682.0.

Traces of what appears to be an underlying band spectrum are visible, but the maxima are of such small intensity that a very long exposure would be required to bring out the structure clearly. Such maxima as

could be distinctly seen have been placed in the Wehnelt column of the table of wave-lengths.

ZINC. [PLATE 3, FIG. 10.]

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3282.5	20	20	10	4680.5	30	40	40
3302.5	30	30	15	4722.5	40	50	50
3345.5	40	50	20	4811.5	50	60	60
3683.5	. .	50	8	4911.5	30	. .	8
4058.0	. .	25	5	4924.0	40	. .	5
4630.0	. .	10	3				

Spark. Zinc electrodes.
Arc. Metallic zinc on carbon electrodes.
Wehnelt. Zinc wire in hydrochloric acid.

Beside the above lines there are present in the spectrum of the Wehnelt the lines of an underlying band spectrum with heads at approximately λ 3848.0, λ 4238.0, λ 4257.0, λ 4299.0, λ 4325.0. The finer detail of these bands, from photographs in the third spectrum, will be given in a later paper. The heads of the flutings of the strongest and longest band have wave-lengths as follows:

4163.2	4193.7	4216.1	4242.4
4170.1	4199.6	4220.2	4247.8
4176.5	4203.9	4226.7	4252.5
4182.4	4208.0	4232.2	4256.9 *Head.*
4187.6	4212.9	4237.8	

The spectrum of a zinc point used as active electrode offers many interesting differences from the spark and arc spectra of the metal.

1. The triplets λ 3282.5, λ 3302.5, λ 3345.5, and λ 4680.0, λ 4722.0, λ 4811.0, are present with about the same relative intensities as in spark and arc. The lines λ 3683.0, λ 4059.0, λ 4630.0, which are strong in the arc and absent from the spark, are present in the Wehnelt spectrum with lower intensities, but about the same ratio of intensity as in the arc. The lines λ 4911.0 and λ 4924.0, strong *spark* lines which are absent

from the arc spectrum, are present in the Wehnelt, but with less intensity, and are not decreased proportionately.

2. These two lines, λ 4911.0 and λ 4924.0, belong to a class which will be referred to again under tin and lead, broad and diffuse, and distinctly different from the other lines of the spark in appearance. The position of these lines in Kayser and Runge's series * has not been determined, and the question as to whether they belong to the same class as the tin lines noticed by Crew † is still an open one.

3. The marked underlying band spectrum. This is so faint as to be difficult of reproduction, though a large part of it may be measured, especially the brighter band from λ 4163.0 to λ 4257.0. Here 19 maxima are visible, but it is in many cases difficult to decide whether lines or the heads of flutings are being measured. This band spectrum seems to be characteristic of this method of producing a spectrum, and the author knows of no other notices or measurements of it.

MERCURY. [Plate 3, Fig. 11.]

Wave-length.	Spark.	Arc	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3278.0	1	. .	3	4348.0	. .	7	3
3342.0	7	20	. .	4359.0	30	40	40
3381.0	. .	. .	10	4916.5	. .	5	2
3543.5	1	6	. .	5217.0	2	. .	. .
3650.5	50	15	50	5426.0	10	. .	. .
3655.0	5	10	8	5461.0	50	100	50
3663.0	7	15	10	5595.0	3	. .	. .
3681.0	. .	8	. .	5678.0	20	. .	. .
3984.0	40	5	4	5769.0	20	50	20
4047.0	30	20	40	5790.0	20	50	20
4078.0	2	15	6				

Spark. Amalgamated copper terminals.
Arc. Metallic mercury on carbon electrodes.
Wehnelt. Platinum point in solution of mercuric nitrate.

* Vid. W. A., **43**, 395 (1894).

† Astrophys. J., **12**, 167 (1900).

The Wehnelt seems to lie about half-way between the arc and the spark in relation of intensity of lines. λ 3278.0 is plainly visible, though of lowest order of intensity in the spark and invisible in the arc spectrum. The lines at λ 3650.0, λ 3655.0, and λ 3663.0 have about the same intensities as in the spark. λ 3984.0 is very feeble, of intensity 4 in the table, as against 40 for the next line, λ 4046.0, and 6 for λ 4078.0. The arc line at λ 4916.5 is plainly visible, while the line at λ 3681.0, also belonging to the arc spectrum, is not to be seen. The spark lines at λ 5426.0 and λ 5678.0 are not present. There is a strong line at λ 3381.0 in the spectrum of the Wehnelt which has not been placed satisfactorily to the credit of any impurity. No traces of a banded spectrum are to be seen.

Tin.

The points of especial interest in the table are: —

1. Marked differences in intensities in spark, arc, and Wehnelt spectra. λ 3283.5 is much weaker in the last than in the spark, and λ 3330.0, λ 3655.5, λ 3801.0, λ 4525.5, λ 5632.0 are much stronger. The spectrum of the Wehnelt is in many parts more like that of the arc.

2. The presence of an underlying band spectrum, containing many flutings, and not present either in the spark or the arc spectrum of the metal. The wave-lengths of these maxima have been placed in the table without certainty as to whether the maximum in question is a sharp line or the head of a fluting. So far as the author knows this spectrum of tin has not been observed under any other circumstances.

3. The appearance of certain lines. Of striking interest in this connection is the pair of lines at λ 5562.0 and λ 5588.0. These lines are strong in the spark, absent from the arc, and of small intensity in the Wehnelt spectrum as compared with the spark. They are also the most striking lines in the spark spectrum on account of their marked breadth and diffuseness. The lines at λ 3283.5 and λ 3352.0 have the same peculiarities in a much less degree, and they also follow the same course in their varying intensities in the three spectra.

A similar change in the latter pair of lines has been observed in the arc between tin electrodes in an atmosphere of nitrogen, these lines being much weaker than in the spark in air.* In ammonia gas and hydrogen they are greatly *enhanced*. The possibility of the formation of metal-hydrogen compounds in the Wehnelt and of a similar influence

* Vid. Porter, Astrophys. J., **15**, 274 (1902).

TIN. [PLATE 3, FIG. 12.]

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3175.0	2	3	2	3821.5	..	..	1 heads ?
3249.0	..	..	4	3837.5	..	..	2
3262.5	15	10	20	4046.5	..	..	1
3273.5	..	..	3	4307.5	..	..	1
3283.5	20	..	3	4382.5	..	..	2
3330.5	3	10	30	4512.0	..	..	1
3352.0	30	..	8	4525.5	8	40	100
3392.0	..	..	1 heads of flutings ?	4586.0	10	..	1
3416.5	..	..	1	4617.3	..	..	2 heads ?
3446.5	..	..	1	4651.5	..	..	1
3472.5	..	..	1	4722.0	..	..	1
3487.3	..	..	4	4810.0	..	..	1
3571.5	..	..	1	4858.0	10	..	5
3589.0	..	..	4	4923.0	2	..	..
3619.0	..	..	1	5100.5	8	..	2
3639.0	..	..	8	5147.5	..	..	1
3655.5	1	8	10	5223.0	4	..	..
3693.2	..	..	1 heads ?	5243.5	..	..	1
3723.4	..	..	2	5290.0	2	..	..
3734.9	..	..	2	5332.0	50	..	7
3746.0	1	..	1	5562.0	100	..	20
3801.0	15	30	80	5588.0	100	..	15
				5632.0	..	10	10
				5798.0	50	..	10

Spark. Tin electrodes.
Arc. Metallic tin on carbon electrodes.
Wehnelt. Tin wire in hydrochloric acid.

of the atmosphere of mixed hydrogen and oxygen is suggested, though other cases (see aluminium and magnesium) seem to indicate the preponderence of the action of the oxygen freed by the dissociation of the water vapor.

Some evidence in the matter is given by the research of Crew * on the arc spectra of metals in hydrogen. The results which seem to have bearing in this case are: —

"I. All lines in the arc spectrum which are affected by hydrogen, whether enhanced or diminished, belong to the spark spectrum also.

"II. Lines which belong to Kayser and Runge's series are unaffected by the change from air to hydrogen."

These conclusions cannot be applied as a whole to the spectra of the Wehnelt, but something very similar to the second of them seems to be true for zinc, tin, and lead. (Vid. lead.)

LEAD. [PLATE 1, FIG. 6.]

Wave-length.	Spark.	Arc.	Wehnelt.	Wave-length.	Spark.	Arc.	Wehnelt.
3573.0	20	20	25	4245.0	100	..	6
3640.0	20	25	40	4387.0	100	..	5
3671.5	10	20	8	4478.0	..	10	..
3683.5	50	20	30	5005.5	6	..	3
3726.0	..	20	..	5045.0	8	..	..
3740.0	30	..	25	5201.5	..	5	..
3854.0	15	..	..	5372.5	10	..	1
4019.5	10	20	8	5546.0	10	..	1
4058.0	100	40	50	5588.0	..	3	..
4062.5	10	8	6	5607.0	10	..	..
4168.0	10	12	5	6002.0	..	4	..
4242.0	10	..	..	6020.0	..	..	10

Spark. Lead electrodes.
Arc. Metallic lead on carbon electrodes.
Wehnelt. Lead wire in hydrochloric acid.

* Ibid., **12**, 167 (1900).

The absence of several of the strong lines of the spark spectrum is of interest. (λ 3854.0, λ 4242.0, etc.) The strong pair of spark lines at λ 4245.0 and λ 4387.0, which is entirely absent from the arc spectrum, is present in the Wehnelt, but with greatly diminished intensity. This pair is one like those already referred to under zinc and tin, differing from the other lines of the spark spectrum in appearance by being broader and more diffuse.

The spectrum of a carbon point in various acids has also been photographed. (See Plate 1, Fig. 1.) None of the plates show any lines or bands which are not directly traceable to impurities in the carbons used. About 90 lines of iron, 12 of calcium, and 2 of aluminium were measured in one case. These lines were superimposed on a continuous spectrum of considerable intensity, but no bands were observed.

Preliminary tests on salts containing complex ions have given results of interest. A carbon or platinum point in a solution of potassium ferrocyanide gives lines of potassium and iron and no new lines. Potassium chromate as electrolyte absorbs all but a small strip of actinic light, but of a dozen lines measured in the vicinity of the D-lines, two were lines of potassium and the rest were lines of chromium, the triplet λ 5204–λ 5208 being strong.

Besides the metals described the following have been photographed in the Wehnelt, both in the first and third spectrum: — copper, nickel, iron, gold, palladium, platinum.

As has been already stated, no effect of the anion has been observed at any time. The breaking up of the chromate ion and the appearance of the lines of metallic chromium in the case of potassium chromate, and the fact that all the salts of the same metal give identical spectra, show this clearly. The facts all point to the high temperature as the cause of the luminescence, and to the probability that the electrolysis plays a purely secondary part.

Although no effect of the anion is observed, the spectra produced by this arrangement are in many cases compound spectra, if we are to accept the sharp distinction of *compound* and *metallic* or elementary spectra as evidenced by the presence or absence of *bands*. Aluminium, magnesium, calcium, barium, give the bands which are ascribed to their oxides, and zinc and tin give fluted spectra which appear to be of the same general type. The presence of free oxygen and hydrogen at a temperature above the point of dissociation of water affords the possibility of a strong oxidizing action on any metal and the opportunity for the

exhibition of an oxide spectrum when the dissociation temperature of the oxide in question lies at a point higher than the dissociation temperature of water. That the free hydrogen in the mixture of gases could under these conditions form metal-hydrogen compounds * seems more than doubtful, yet the variations between Wehnelt and spark and arc in air bear a striking resemblance to the variations in the arc spectra of the same metals in air and hydrogen, and in the latter case the necessity for the assumption of such metal-hydrogen compounds seems to be felt.†

Although the spectra under discussion are in many ways similar to those produced by allowing the spark to pass from a metallic point to a solution of a salt, many of the characteristic bands of compounds produced by the latter method are absent in the Wehnelt. Compound spectra, varying from salt to salt, are the rule in the more volatile metals ‡ when the spark passes to a solution of one of their salts. The point used gives, in the Wehnelt, all the strong lines of the metal, even of platinum, while in the other method the lines of the electrode are but faint.

The tables and plates show the following general points of especial interest: —

1. The lines of the Wehnelt spectra include some which have been usually ascribed to the spark and some which have been ascribed to the arc; usually the spectrum is closely allied to that produced in the spark, but often *some of the strongest lines are missing.* Other researches which give evidence as to the effect of varying conditions on spectrum lines serve to strengthen the conclusion which must be drawn: — that there is no sharp boundary between arc and spark, and that the transition from "arc" spectrum to "spark" spectrum is a gradual and continuous one.

2. Under constant conditions a spectrum may contain the strongest lines of the condensed spark and at the same time lines usually ascribed to the flame. §

3. Under the same conditions the "oxide bands" may be present at the same time as the strong spark lines. §

4. Under the same conditions the spectrum of zinc contains, beside lines belonging to both spark and arc spectra, a band spectrum not

* Vid. Liveing and Dewar, l. c.

† Vid. Basquin, l. c., and Porter, l. c.

‡ Vid. Lecoq. Spectres. Lum., atlas.

§ See on these points Liveing and Dewar, l. c.; also Proc. Roy. Soc., **32**, 189 (1881).

hitherto observed under any conditions. The same is true of the spectrum of tin in the Wehnelt interrupter.

5. Certain lines which are of broad, diffuse appearance in the spark and are absent from the arc spectrum of the metal, are present in the Wehnelt spectrum, but much decreased in intensity. The metals which show this phenomenon most sharply are zinc, tin, and lead.

The first thought is, of course, that we are dealing with a complicated process involving an entire series of temperatures from that sufficient to give the band spectrum of a compound to that necessary to produce the strongest lines of a difficultly fusible metal like platinum or chromium, and that the point and the space about it pass through this series of temperatures at each interruption of the current. The result would be a spectrum which was the sum of the spectra corresponding to the various temperatures through which the system passes. Such a conclusion should be evidenced by the presence of all the lines of all the spectra, and if we are to couple each spectrum with a definite temperature we should expect the resulting composite to be complete. But in none of the cases examined are all of the lines of the various spectra present. Some strong lines are and some are not present in normal intensity. So this conclusion, though perhaps the simplest consistent with our present knowledge of temperature and spectra and the relation between them, seems not to explain the facts.

The interrupting action in the Wehnelt is undoubtedly caused by the intense heating due to the high current density about the small point. The heat vaporizes and then dissociates the water into hydrogen and oxygen, as has been shown by the analyses of Voller and Walter * and others. That spectra like those of the oxyhydrogen flame should result from the explosion of the mixed gases by the hot metal in the cooler parts of the gaseous envelope is not surprising, it is rather remarkable that not more of the characteristic flame spectra were observed. At the same time the great affinity for oxygen of such metals as aluminium, magnesium, calcium, and barium might explain the appearance of the bands belonging to the oxides of these metals.

The one point which is difficult of explanation by any reasoning based on the assumption of a varying temperature is the absence of some of the characteristic strong lines, while others usually ascribed to the same temperature are present.

* L. c.

It seems probable that the environment of the point does pass through a very great range of temperature with each interruption of the current. There seems to be no reason for believing that the same is not true of the spark in air and of the arc. In the spark in air the discontinuity of succeeding oscillations is quite complete, and the necessity for an explanation of the absence of lines ascribed to lower temperatures seems as evident as in the case at hand. It seems probable that all three of these spectra, spark, arc, and Wehnelt, are composites, though this is not so evident in the usual methods of spectrum production.

In the Wehnelt, reversals were not observed in any case. This is remarkable since Hale,* and Hale and Kent,† and Lockyer, ‡ and others who have examined the spectra of the arc under liquids have shown that a very strong tendency toward reversal may exist under these circumstances. The mechanism of spectrum production in the two cases must be very different.

Lockyer gives as the result of his investigations and as the basis of many deductions four distinct stages of temperature corresponding to the spectra of metals as they are produced in the laboratory. They are:

"1. The flame spectrum, consisting of a few lines and flutings only, including several well-marked lines, some of them arranged in triplets.

"2. The arc spectrum, consisting of many lines.

"3. The spark spectrum, differing from the arc spectrum in the enhancement of some of the short lines and the reduced relative brightness of others.

"4. A spectrum consisting of a relatively very small number of lines which are enhanced in the spark. This latter spectrum is produced at a temperature which is that of the very centre of the spark."

Lockyer has also made frequent use in his writings of a diagram showing a series of furnaces of increasing temperature, spectra being used to designate the temperature in each. The flame is taken as the lowest, the arc next, and then the spark, followed in application to astrophysical comparisons by the spectrum of a typical cooler star, then hotter ones, and so on. We have in the Wehnelt interrupter a "furnace" in which under constant experimental conditions a banded (compound) spectrum like that found for aluminium, and a pure line spectrum like that found for platinum may be produced. The amount of current passing in the two cases is the same, the other factors of the experiment (composition

* Astrophys. J., **15**, 190 (1902).

† Ibid., **17**, 155 (1903).

‡ Ibid., **15**, 190 (1902).

of electrolyte, size of electrodes, etc.) remain constant, and there is every reason to believe that the maximum temperature reached is the same in the two cases. Any criterion of the temperature corresponding to either of these spectra would appear to be wanting unless they correspond to the *same* temperature. Nor does the fact of the absence of some of the strong lines of a metal appear to offer any measure, however qualitative, of the temperature, since other strong lines usually belonging to the same temperature are present.

It is certainly very easy to be led into reasoning in a circle in a case where much of our knowledge of temperatures has been deduced from observations on spectra, and much of our theory as to the correspondence of certain spectra with certain temperatures has been drawn ultimately from the same source.

Jefferson Physical Laboratory,
Harvard University, Jan. 15, 1904.

PLATE 1.

FIG. 1. Spectrum of carbon point in hydrochloric acid. (Lines of impurities, which are iron, calcium, and aluminium.)

FIG. 2. Spectrum of carbon point in solution of sodium chloride.

FIG. 3. Spectrum of carbon point in solution of potassium chloride.

FIG. 4. Spectrum of platinum point in solution of barium chloride.

FIG. 5. Spectrum of platinum point in solution of strontium chloride.

FIG. 6. *a*. Spectrum of spark in air between lead terminals.
b. Spectrum of arc in air. Metallic lead on carbon terminals.
c. Spectrum of lead point in hydrochloric acid.

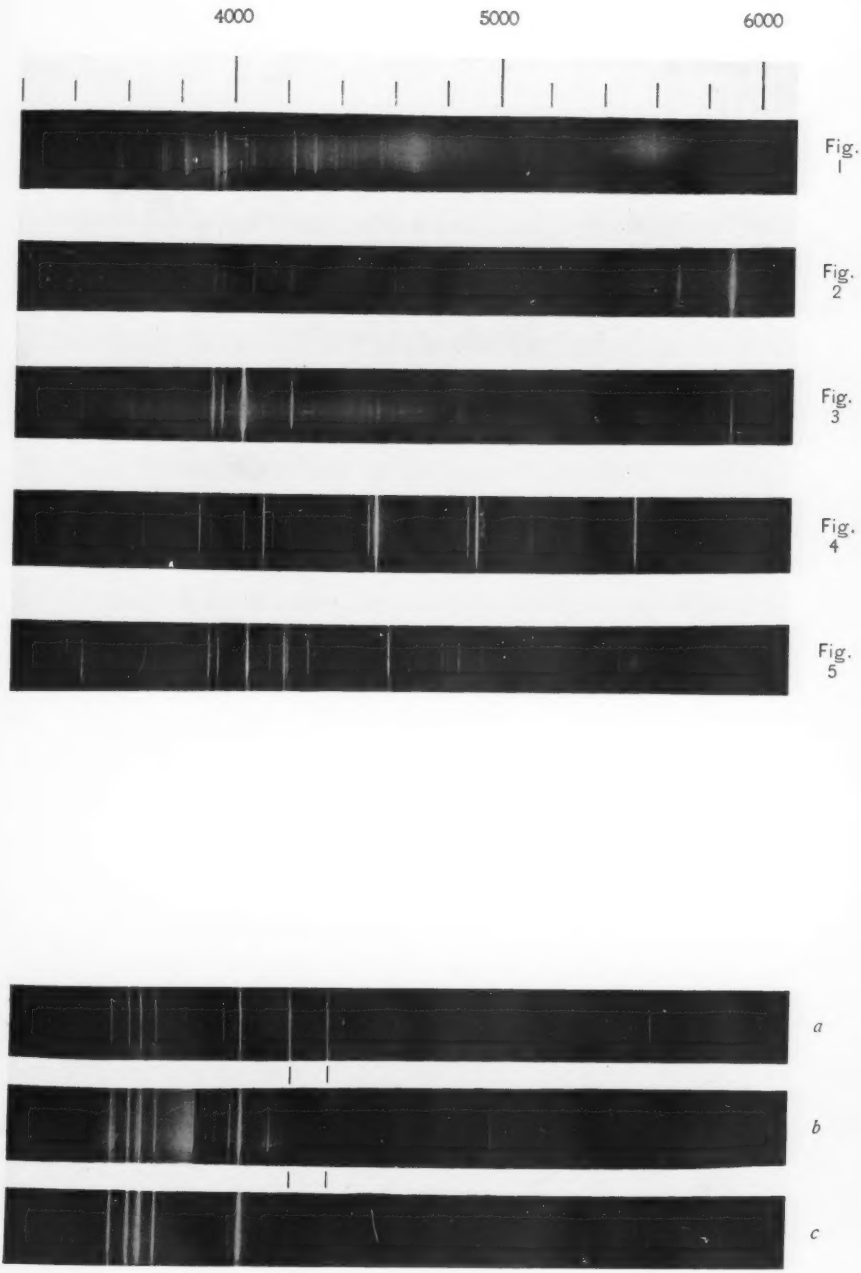

Fig. 6

PLATE 2.

FIG. 7. *a*. Spectrum of arc in air. Lithium chloride on carbon terminals.
b. Spectrum of spark in air. Lithium chloride on carbon terminals.
c. Spectrum of carbon point in solution of lithium chloride.

FIG. 8. *a*. Spectrum of spark in air between magnesium terminals.
b. Spectrum of arc in air. Metallic magnesium on carbon terminals.
c. Spectrum of magnesium point in hydrochloric acid.

FIG. 9. *a*. Spectrum of spark in air between aluminium terminals.
b. Spectrum of arc in air. Metallic aluminium on carbon terminals.
c. Spectrum of aluminium point in hydrochloric acid.

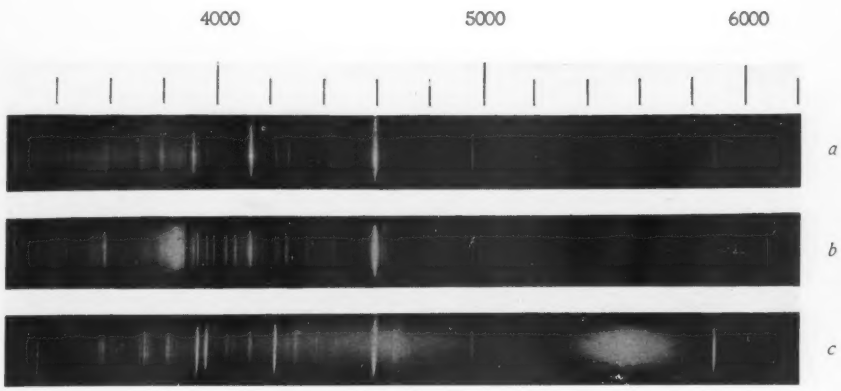

Fig. 7

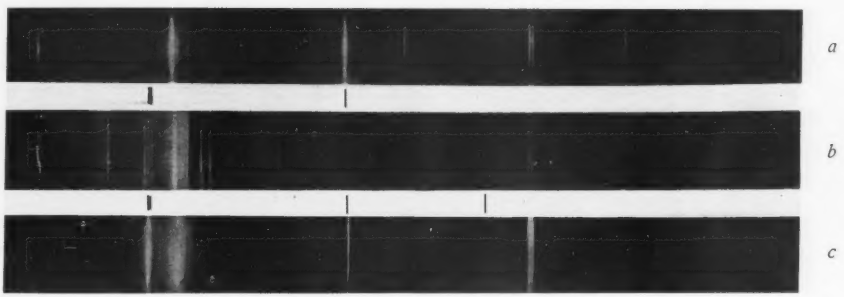

Fig. 8

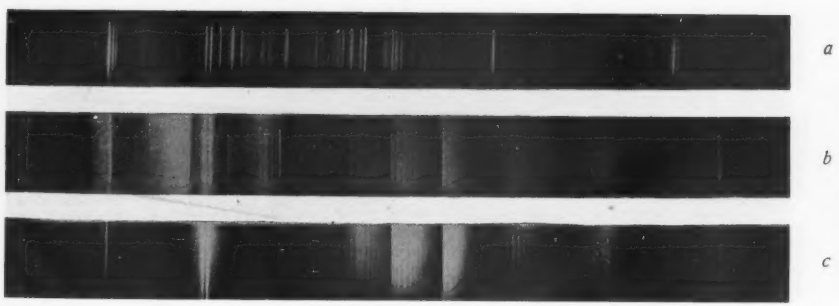

Fig. 9

PLATE 3.

FIG. 10. *a*. Spectrum of spark in air between zinc terminals.
b. Spectrum of arc in air. Metallic zinc on carbon terminals.
c. Spectrum of zinc point in hydrochloric acid.

FIG. 11. *a*. Spectrum of spark in air between amalgamated copper terminals.
b. Spectrum of arc in air. Metallic mercury on carbon terminals.
c. Spectrum of platinum point in solution of mercuric nitrate.

FIG. 12. *a*. Spectrum of spark in air between tin terminals.
b. Spectrum of arc in air. Metallic tin on carbon terminals.
c. Spectrum of tin point in hydrochloric acid.

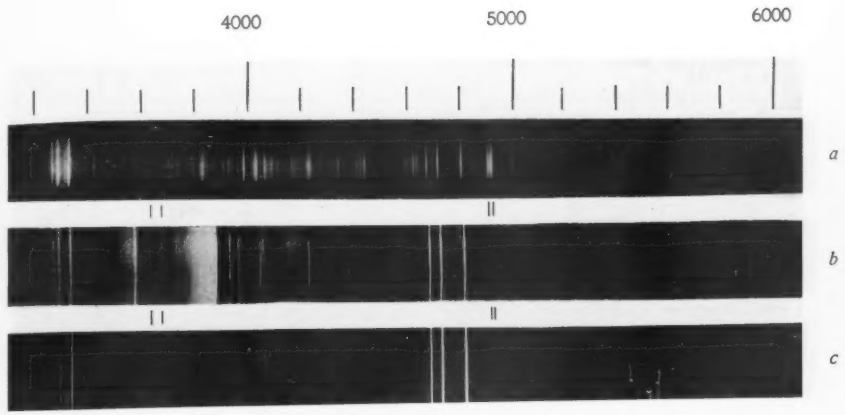

Fig. 10

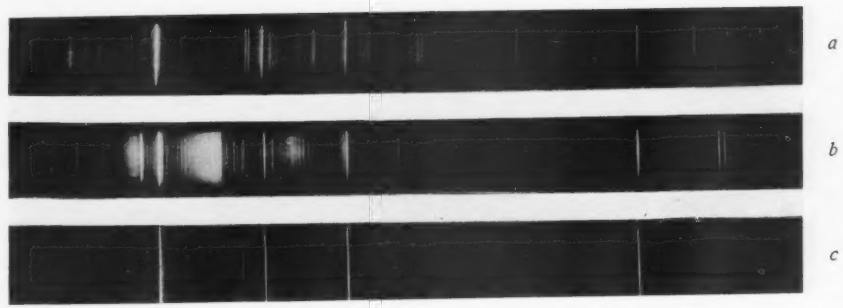

Fig. 11

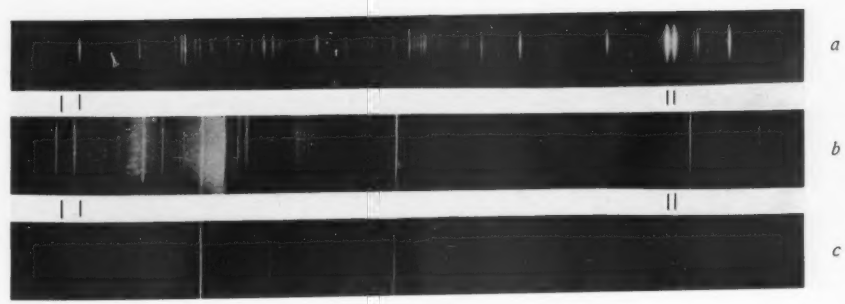

Fig. 12